



Diagnostic, treatment, and prevention protocols for canine heartworm infection in animal sheltering agencies

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ABSTRACT

The high prevalence of heartworm infection in shelter dogs creates a dilemma for shelter managers, who frequently operate with insufficient funding, staffing, and expertise to comply with heartworm guidelines developed for owned pet dogs. The purpose of this study was to survey canine heartworm management protocols used by 504 animal sheltering agencies in the endemic states of Alabama, Florida, Georgia, and Mississippi. Open-admission shelters, which tended to be larger and more likely to perform animal control functions, were less likely (41%) to test all adult dogs than were limited-admission shelters (80%), which tended to be smaller non-profit humane agencies, and foster programs (98%) based out of private residences. Open-admission shelters were more likely to euthanize infected dogs (27%) or to release them without treatment (39%), whereas limited-admission shelters and foster programs were more likely to provide adulticide therapy (82% and 89%, respectively). Of the 319 agencies that treated infections, 44% primarily used a standard two-dose melarsomine protocol, and 35% primarily used a three-dose split-treatment melarsomine protocol. Long-term low-dose ivermectin was the most common treatment used in 22% of agencies. Open-admission shelters were less likely (35%) to provide preventive medications for all dogs than were limited-admission shelters (82%) and foster programs (97%). More agencies used preventives labeled for monthly use in dogs (60%) than ivermectin products labeled for livestock (38%). The most common reason diagnostic testing and preventive medication was not provided was cost. These results indicate a lack of protocol uniformity among agencies and insufficient resources to identify, treat, and prevent infection. Sheltering agencies and companion animal health industries should develop guidelines that are feasible for use in sheltering agencies and provide improved access to preventive and treatment strategies for management of *Dirofilaria immitis*.

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1. Introduction

Despite the availability of highly effective preventive medications, canine *Dirofilaria immitis* infections continue to spread throughout the United States (Bowman et al., 2007, 2009). Although the areas of highest prevalence

remain in the Southeast, Gulf Coast, and Mississippi River Valley, regionally endemic areas have been documented in all states except Alaska. Possible reasons for the expanding range of heartworm infection include climate change, agricultural irrigation, expansion of mosquito vectors, growing range of non-domestic canid hosts, such as coyotes, and movement of microfilaremic dogs.

The American Heartworm Society (AHS) guidelines for canine heartworm management call for administration of heartworm preventive medication for all dogs by 8 weeks of age (Rubin et al., 2010). Poor compliance

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continues to impede heartworm control, and it is estimated that less than 50% of pet dogs receive preventive medication year-round (Bowman et al., 2007; Gates and Nolan, 2010). A national survey of more than 18,000 veterinary clinics reported more than 240,000 new cases of heartworm infection diagnosed in pet dogs in 2001 (McCall, 2005). Another survey of 2573 veterinary clinics revealed 43,500 pet dogs diagnosed with heartworm infection from more than 3 million dogs tested in 2001–2007 (Bowman et al., 2009). Prevalence was higher in the Southeast (3.9%) than in the other regions of the country (0.6–1.2%).

An estimated 3 million to 4 million lost and unwanted dogs enter animal shelters each year, and in many agencies, a majority of dogs may be euthanized within a few days of admission. Shelter managers must often make difficult decisions regarding the allocation of limited financial, staff, and facility resources for the best cost–benefit ratio. Management of infectious diseases is one area in which compromises are sometimes made. Heartworm infections are especially difficult because of the high cost and length of time required for treatment (Nelson, 2009). Even routine diagnosis and prevention may exceed some sheltering agencies' capacity for care.

Failure to recognize heartworm infection can lead to development of cardiopulmonary disease, to the adoption of infected animals to the unsuspecting public, and to transmission in the community, whereas failure to administer preventive medication can lead to transmission within the facility itself. The increasing trend of transporting overpopulated homeless dogs from Southern regions with high shelter euthanasia rates to Northern regions for adoption may coincide with currently expanding mosquito ranges to increase the rate of heartworm transmission in areas of historically low risk (Bowman, 2010).

In heartworm-endemic regions, the prevalence of infection in shelter dogs may be more than 10 times the prevalence in locally owned pet dogs. In the Southeast, infection rates have been reported to range from 10% to 50% of adult dogs in animal sheltering agencies (Levy et al., 2007, *in press*; Tzipory et al., 2010) compared with rates of 1–7% in owned pet dogs seen in private veterinary clinics (Bowman et al., 2009). This is likely due to lack of preventive medications provided to unwanted and neglected pets or to free-roaming homeless dogs prior to impoundment. The result is that sheltering agencies are much more likely to encounter infected dogs than are local veterinary clinics.

Although guidelines exist for vaccination of dogs in sheltering agencies (Paul et al., 2006), comparable guidelines tailored for this unique setting are not available for many other veterinary procedures, including management of heartworm infection. Guidelines developed for pet dogs are often impractical in sheltering agencies due to limited funding, staffing, and technical expertise therefore managers must make their own adaptations to manage heartworm infection, often in the absence of veterinary consultation. The purpose of this study was to determine canine heartworm protocols currently used by sheltering agencies in an endemic region.

2. Materials and methods

2.1. Sample population

Animal sheltering agencies, including traditional shelters with central animal housing facilities, sanctuaries, pet foster programs, and adoption programs based in veterinary clinics, operate as independent agencies in the United States. No registries exist that systematically catalog agencies in a central directory. A list of animal sheltering agencies in Alabama, Florida, Georgia, and Mississippi was created by consolidating existing directories from national animal welfare organizations, searching online pet adoption programs, and contacting every county in the four states. The final list used for the survey contained information for 1483 animal sheltering agencies in Alabama (211), Florida (742), Georgia (439), and Mississippi (91).

2.2. Survey instrument

A survey was developed to determine each agency's current protocols regarding diagnosis, prevention, and treatment of heartworm infection in dogs and cats. The survey was loaded into an Internet-based survey response tool (SurveyMonkey LLC, Portland, OR). A pilot survey was administered to a focus group of 50 sheltering agencies in Florida to seek feedback on content, clarity, and ease of use, the results of which were used to create the final survey instrument. The survey was not anonymous, and contact information was requested to enable clarification of responses if necessary. If respondents had all required information at hand, the survey could be completed in approximately 10 min. A section concerning agency demographic information included five questions identifying the organization type, presence of a shelter facility, admission policy, spay/neuter availability, and total admission numbers for dogs and cats in 2008. The section concerning heartworm protocols included questions addressing protocols both for cats and for dogs: 10 questions each regarding diagnostic testing, three questions each regarding treatment, and eight questions each regarding the administration of preventive medications. Space was also provided for free-text comments regarding shelter heartworm protocols. This report describes protocols reported for dogs. Information regarding heartworm protocols for sheltered cats is described in the companion report (Dunn et al., 2011).

2.3. Survey administration

The survey was administered between June and July 2009. Each agency was initially contacted via email (or telephone if an email address was not available) encouraging completion of the survey by accessing an Internet link. Follow-up agency email invitations were sent at 5, 9, and 13 days post survey launch. Study staff members were available to assist in the collection of survey results from those agencies without Internet access or that indicated a preference for completing the survey in a different manner. Options included completion of the survey by telephone or in writing via a printed copy. Telephone calls were initiated

to all agencies that had not completed the survey within 14 days. Most telephone calls were completed during business hours for an opportunity to contact a working employee knowledgeable of the agency's heartworm protocols. Calls were also made in the evening and on weekends. Non-responding agencies received a postcard mailer 1 month post survey launch. In addition to contacting the agencies on the compiled list, a non-targeted appeal for participation was made via the electronic mailing list of the Association of Shelter Veterinarians.

2.4. Data collection and analysis

Survey responses were audited for completeness and internal consistency as they were received. Respondents were contacted for clarification if necessary. Agencies were classified according to their funding source, admission policies, use of a shelter facility, and number of dogs admitted in 2008. Municipal shelters serve as animal control facilities and are funded by local governments, whereas non-profit animal welfare agencies are private charitable organizations. In some cases, non-profit agencies may have contracts to perform animal control functions and receive funding from municipalities. Open-admission agencies accept all dogs brought to them, whereas limited-admission agencies accept dogs selectively based on criteria such as space availability or breed. Although exceptions exist, in general, open-admission shelters are more likely to use euthanasia to control the shelter population and limited-admission shelters are more likely to refuse admissions when the shelter is at capacity. Agencies also differ according to whether dogs are housed in a central shelter facility or are dispersed in foster homes. Dog sanctuaries are unique in that dogs are admitted with the expectation that most will remain at the agency for life rather than being adopted or euthanized. Some agencies have multiple functions, such as a shelter facility with a foster program. In this case, agencies were asked to complete the survey based on the agency's primary function. A small number of veterinary clinics that house adoptable dogs also submitted survey responses.

3. Results

3.1. Survey response

Of the 558 agencies that responded, 504 admitted dogs in 2008 (Table 1). Of those that admitted dogs, 383 (76%) were non-profit organizations, 289 (57%) had limited-admission policies, and 321 (64%) utilized a central shelter facility for housing at least some of their dogs. Although the majority of agencies (311; 62%) were small organizations that admitted fewer than 500 dogs in 2008, the larger agencies (193; 38%) together admitted at least twice as many dogs as the small agencies combined. Of the 40 largest agencies admitting 5000 or more dogs, most (36; 90%) were open-admission shelters, and most (33; 83%) were municipal animal control shelters or non-profit shelters with municipal animal control contracts.

Table 1 Characteristics of 504 animal sheltering agencies in the Southeastern United States that provided information regarding their canine heartworm protocols.

	No. of agencies by state (%)					No. of agencies relative to no. of dogs they admitted in 2008 (%)			
	Alabama (n = 70)	Florida (n = 253)	Georgia (n = 143)	Mississippi (n = 38)	≤499 (n = 311) (n = 53)	500–999 (n = 100)	1000–4999 (n = 32)	5000–9999 (n = 8)	≥10,000 (n = 8)
Agency funding source									
Municipal animal control	15 (21)	47 (19)	38 (27)	10 (26)	20 (6)	15 (28)	48 (48)	21 (66)	6 (75)
Private non-profit animal welfare	44 (63)	185 (73)	88 (62)	19 (50)	274 (88)	35 (66)	20 (20)	6 (19)	1 (13)
Private non-profit with animal control contract	10 (14)	14 (5)	14 (10)	9 (24)	8 (3)	3 (6)	30 (30)	5 (16)	1 (13)
Private veterinary hospital	1 (1)	7 (3)	3 (2)	0	9 (3)	0	2 (2)	0	0
Primary agency function									
Animal shelter	46 (66)	144 (57)	97 (68)	34 (89)	140 (45)	45 (85)	96 (96)	32 (100)	8 (100)
Foster program	15 (21)	92 (36)	40 (28)	4 (11)	142 (46)	7 (13)	2 (2)	0	0
Veterinary clinic	3 (4)	12 (5)	6 (4)	0	18 (6)	1 (2)	2 (2)	0	0
Sanctuary	6 (9)	5 (2)	0	0	11 (4)	0	0	0	0
Animal admission policy									
Open admission	29 (41)	96 (38)	65 (45)	25 (66)	73 (23)	22 (42)	84 (84)	28 (88)	8 (100)
Limited admission	41 (59)	157 (62)	78 (55)	13 (34)	238 (77)	31 (58)	16 (16)	4 (12)	0

3.2. Heartworm diagnostic testing

A majority of agencies (361; 72%) tested all adult dogs for heartworm infection; 82 (16%) tested only a portion of adults; and 61 (12%) performed no testing at all (Table 2). The use of heartworm diagnostic testing was largely affected by the type of agency, with open-admission shelters more likely than other types to forgo testing altogether. Foster programs, limited-admission shelters, and veterinary clinics were most likely to comply with the AHS guidelines to test all adult dogs. Agencies that tested only a portion of adults were asked a series of questions to identify how individual dogs were selected for testing. Although protocols varied widely, dogs were sometimes tested if they were being evaluated for adoption or transfer to another agency, involved in cruelty investigations, or had clinical signs consistent with heartworm disease. The most common reason given for not testing any dogs for heartworm infection was expense (29; 48%), and the second most common response was that testing was deemed unnecessary since treatment of infected dogs was not an option even if infected dogs were identified (20; 33%).

Antigen tests were the test of choice for 288 (65%) of 443 agencies that tested at least some dogs, followed by 25 (6%) that relied on filarial tests. A combination of tests was routinely used by 72 (16%) agencies. A total of 58 (13%) agencies reported the method of testing was determined by a private veterinarian, and the agency was unaware of which type of test was used. Dogs in animal shelters with a central facility were more likely to be tested at the shelter, whereas dogs in foster programs were more likely to be tested at veterinary clinics. Diagnosis of heartworm infection influenced decisions regarding adoptability, euthanasia, and acceptance for admission by some agencies. The outcome of dogs diagnosed with heartworm infection varied widely depending on the type of agency housing the dogs. Euthanasia or release without treatment was more common in open-admission shelters whereas release following treatment was more common in limited-admission shelters and foster programs.

3.3. Heartworm treatment

A majority of agencies that tested dogs followed up a diagnosis of infection with some form of adulticide therapy in at least some of the infected dogs (Table 3). Of the 443 agencies that tested dogs, 174 (39%) reported they treated all infected dogs, 217 (49%) treated some dogs, and 52 (12%) did not treat any dogs.

Of the 322 agencies that reported standardized treatment protocols, 139 (43%) primarily used a standard two-dose melarsomine protocol, and 113 (35%) primarily used a three-dose split-treatment melarsomine protocol. Long-term low-dose ivermectin was the most common treatment used in 70 (22%) agencies. A total of 69 (18%) agencies reported that the treatment method varied according to the recommendations of private veterinarians. A variety of adjunctive medications were employed during adulticide therapy, including ivermectin, corticosteroids, nonsteroidal anti-inflammatory drugs, and other medications. Doxycycline was used by less than half of

agencies that treated dogs for heartworm infection. Ivermectin was the most common drug administered to dogs that did not receive adulticide therapy, and doxycycline was uncommonly used in untreated dogs.

3.4. Heartworm prevention

A total of 352 (70%) sheltering agencies complied with AHS recommendations to provide heartworm preventive medications to all dogs (Table 4). Limited-admission shelters, foster programs, veterinary clinics, and sanctuaries were more likely to use preventives than were open admission shelters. Similar to the situation for diagnostic testing, the 58 agencies (12%) that provided preventives for only some dogs in their care used variable criteria for selection, including those dogs being evaluated for adoption or transfer to another agency, those involved in cruelty investigations, or those with clinical signs consistent with heartworm disease. The most common reason given by the 94 agencies that never used preventive medication in dogs was that it was too expensive (56; 60%). The second most common response (25; 27%) was the belief that preventive medication should not be given if diagnostic testing was not performed first.

Products labeled for monthly use in dogs were most commonly used for heartworm prevention, followed by ivermectin products labeled for livestock. Off-label use of livestock ivermectin was more common at animal shelters with a central facility than at other agencies. Approximately half of agencies administered preventive medication only after a negative heartworm test, whereas others administered it at the time of admission, on a predetermined monthly schedule, after selection for adoption or transfer, or after the legal hold period expired. A small number of agencies withheld preventive medication from puppies due to the belief that only adults should receive preventives.

4. Discussion

In this study, sheltering agencies reported that the primary reason for not adhering to published heartworm management guidelines was the cost associated with providing the care. Smaller agencies, limited-admission shelters, private nonprofit humane agencies, and foster programs were more likely to comply with AHS management guidelines than were large agencies and open-admission animal control shelters. Thus, although the majority of individual agencies generally complied with at least portions of the AHS guidelines, the majority of sheltered dogs likely did not receive adequate heartworm management. Larger shelters frequently admit far more dogs than they can rehome and may euthanize a large proportion of dogs after a short stay in the shelter. In this situation, investment in heartworm diagnosis and prevention may be deemed less feasible than in smaller agencies that keep each dog until it can be rehabilitated and adopted. Regardless of the organizational structure of sheltering agencies, managers must allocate their finite financial and staff resources to best serve a variety of competing needs. These needs include protecting the public from danger-

Table 2
Canine heartworm diagnostic testing protocols in 504 animal sheltering agencies in the Southeastern United States.

	No. of agencies (%)				
	Open-admission shelters	Limited-admission shelters	Foster programs	Veterinary clinics	Sanctuaries
Heartworm testing of dogs >6 months old	(n = 184)	(n = 137)	(n = 151)	(n = 21)	(n = 11)
All dogs are tested	75 (41)	110 (80)	148 (98)	21 (100)	7 (64)
Some dogs are tested	65 (35)	14 (10)	2 (1)	0	1 (9)
No dogs are tested	44 (24)	13 (9)	1 (1)	0	3 (27)
Primary reason no dogs are tested	(n = 44)	(n = 13)	(n = 1)	(n = 0)	(n = 3)
Too expensive	18 (41)	7 (54)	1 (100)	NA	3 (100)
Test reliability concerns	0	1 (8)	0	NA	0
Regional risk of heartworm infection is low	0	0	0	NA	0
Takes too much time	0	0	0	NA	0
Limited qualified staff	2 (4)	1 (8)	0	NA	0
Tests are unavailable	6 (13)	2 (15)	0	NA	0
Positive result may hinder adoption or transfer	0	0	0	NA	0
Treatment not provided even if infected	18 (41)	2 (15)	0	NA	0
Most commonly used heartworm diagnostic tests	(n = 140)	(n = 124)	(n = 150)	(n = 21)	(n = 8)
Filaria test	13 (9)	5 (4)	6 (4)	1 (5)	0
Antigen test	90 (65)	91 (73)	84 (56)	18 (86)	5 (63)
Combination of tests	24 (17)	15 (12)	30 (20)	2 (9)	1 (12)
Determined by private veterinarian	13 (9)	13 (11)	30 (20)	0	2 (25)
Location of heartworm testing	(n = 140)	(n = 124)	(n = 150)	(n = 21)	(n = 8)
Tested prior to arrival at agency	1 (1)	6 (5)	11 (7)	0	0
Tested at agency	100 (71)	53 (43)	3 (2)	11 (52)	2 (25)
Tested at private veterinary clinic	32 (23)	50 (40)	94 (63)	4 (19)	6 (75)
Tested at outside laboratory	4 (3)	1 (1)	6 (4)	0	0
Tested at various locations	3 (2)	14 (11)	36 (24)	6 (29)	0
Heartworm diagnosis affects admission decisions	(n = 184)	(n = 137)	(n = 151)	(n = 21)	(n = 11)
Yes	20 (11)	48 (35)	53 (35)	6 (29)	0
No	164 (89)	89 (65)	98 (65)	15 (71)	11 (100)
Heartworm diagnosis affects euthanasia decisions	(n = 140)	(n = 124)	(n = 150)	(n = 21)	(n = 8)
Yes	99 (71)	41 (33)	26 (17)	9 (43)	0
No	41 (29)	83 (67)	124 (83)	12 (57)	8 (100)
Most common outcome for heartworm-infected dogs	(n = 140)	(n = 124)	(n = 150)	(n = 21)	(n = 8)
Euthanasia	38 (27)	6 (5)	3 (2)	1 (5)	0
Offered for adoption or transfer without treatment	55 (39)	15 (12)	11 (7)	2 (9)	1 (13)
Offered for adoption or transfer following treatment	47 (34)	102 (82)	133 (89)	18 (86)	5 (62)
Kept in lifelong care at agency	0	1 (1)	3 (2)	0	2 (25)
Selection of dogs for testing if not all tested					
Dogs evaluated for adoption or transfer	(n = 64)	(n = 14)	(n = 2)	(n = 0)	(n = 0)
All dogs are tested	31 (48)	4 (29)	0	NA	NA
Some dogs are tested	30 (47)	10 (71)	1 (50)	NA	NA
No dogs are tested	3 (5)	0	1 (50)	NA	NA
Dogs with signs of heartworm disease	(n = 61)	(n = 13)	(n = 2)	(n = 0)	(n = 1)
All dogs are tested	14 (23)	1 (8)	0	NA	1 (100)
Some dogs are tested	44 (72)	11 (85)	2 (100)	NA	0
No dogs are tested	3 (5)	1 (8)	0	NA	0
Dogs held for cruelty or legal cases	(n = 61)	(n = 10)	(n = 1)	(n = 0)	(n = 0)
All dogs are tested	21 (34)	2 (20)	0	NA	NA
Some dogs are tested	30 (49)	6 (60)	1 (100)	NA	NA
No dogs are tested	10 (16)	2 (20)	0	NA	NA
Lifelong sanctuary dogs	(n = 16)	(n = 7)	(n = 0)	(n = 0)	(n = 1)
All dogs are tested	6 (37)	2 (29)	NA	NA	0
Some dogs are tested	10 (62)	4 (57)	NA	NA	1 (100)
No dogs are tested	0	1 (14)	NA	NA	0

Table 3Most commonly used heartworm treatment protocols in 443 animal sheltering agencies that perform diagnostic testing for *D. immitis* in dogs.

	No. of agencies (%)				
	Open-admission shelters	Limited-admission shelters	Foster programs	Veterinary clinics	Sanctuaries
Type of heartworm adulticide therapy provided	(n = 140)	(n = 124)	(n = 150)	(n = 21)	(n = 8)
No treatment is provided	44 (31)	6 (5)	2 (1)	0	0
Surgical removal of heartworms	0	0	0	0	0
Melarsomine standard two-dose protocol	36 (26)	50 (40)	40 (27)	8 (38)	5 (63)
Melarsomine split-dosing three-dose protocol	22 (16)	32 (26)	48 (32)	10 (48)	1 (13)
Low-dose long-term ivermectin	17 (12)	21 (17)	27 (18)	3 (14)	2 (25)
Determined by private veterinarian	21 (16)	15 (12)	33 (22)	0	0
Adjunctive treatments administered during adulticide therapy ^a	(n = 168)	(n = 227)	(n = 300)	(n = 48)	(n = 10)
None	15 (9)	11 (5)	25 (8)	0	1 (10)
Aspirin	8 (5)	9 (4)	24 (8)	4 (8)	0
Nonsteroidal anti-inflammatory drug	31 (18)	30 (13)	32 (11)	7 (15)	1 (10)
Narcotic analgesics	3 (2)	9 (4)	10 (3)	4 (8)	0
Corticosteroids	15 (9)	40 (18)	43 (14)	7 (15)	1 (10)
Doxycycline	31 (18)	49 (22)	61 (20)	11 (23)	2 (20)
Ivermectin	28 (17)	44 (19)	51 (17)	11 (23)	3 (30)
Antibiotics	27 (16)	17 (7)	34 (11)	1 (2)	2 (20)
Determined by private veterinarian	10 (6)	18 (8)	20 (7)	3 (6)	0
Treatments administered in the absence of adulticide therapy ^a	(n = 135)	(n = 93)	(n = 128)	(n = 23)	(n = 8)
None	55 (41)	12 (13)	4 (3)	1 (4)	0
Aspirin	2 (1)	4 (4)	5 (4)	0	0
Nonsteroidal anti-inflammatory drug	1 (1)	3 (3)	3 (2)	1 (4)	0
Narcotic analgesics	0	1 (1)	2 (2)	2 (9)	0
Corticosteroids	2 (1)	7 (8)	7 (5)	1 (4)	1 (13)
Doxycycline	13 (10)	11 (12)	21 (16)	6 (26)	2 (25)
Ivermectin	30 (22)	34 (37)	52 (41)	8 (35)	3 (38)
Antibiotics	4 (3)	6 (6)	4 (3)	1 (4)	0
Determined by private veterinarian	28 (21)	15 (16)	30 (23)	3 (13)	2 (25)

^a Multiple selections possible.

ous animals and animal nuisances, rescuing animals from neglect, fighting animal cruelty, enforcing animal laws, sheltering homeless animals, and rehoming animals.

The majority of the 61 agencies that never performed testing of dogs were open-admission shelters. Cost was the primary reason testing was not performed, followed closely by the fact that treatment was not available at some agencies for any dogs found to be infected. This approach transfers responsibility for identification of heartworm-infected dogs to adopters and their personal veterinarians. It also increases the risk that heartworm-infected dogs will be released into the community to serve as a source of infection for other dogs. Antigen detection tests were the most common form of testing. Some agencies relied solely on filarial tests, which are less expensive than antigen tests but are also less sensitive (Courtney and Zeng, 2001). More than a third of agencies that tested factored the diagnosis of heartworm infection in euthanasia decisions. Failure to comply with AHS guidelines to test all dogs for infection annually is not limited to sheltering agencies. In a previous survey of heartworm protocols used by veterinary clinics in the western United States where 1.5% of tested dogs were infected, only 51% of clinics recommended annual testing of dogs (Bowman et al., 2007).

Of the 443 agencies that tested at least some dogs for heartworm infection, 52 did not perform any kind of adulticide therapy.

When adulticide therapy was performed, melarsomine was most commonly used. The conventional two-dose method in which injections are administered 24 h apart was slightly more common than the split-dosing method now recommended by the AHS (Rubin et al., 2010). The split-dose method calls for three doses of melarsomine in which one injection is given, followed by two more injections a month later. The AHS considers the split-dosing protocol to be safer and more efficacious and recommends it for all dogs regardless of clinical disease status. In sheltering agencies, the medical benefits of the split-dosing protocol must be weighed against a 50% increase in drug costs and a longer treatment time, which can lead to shelter crowding and reduce quality of life if dogs are kept in the facility throughout the treatment period. Although the AHS recommends melarsomine as the drug of choice for adulticide therapy, guidelines also state that if adulticide treatment is contraindicated or unavailable, ivermectin may be used long-term with doxycycline. Ivermectin is a macrocyclic lactone with both microfilaricidal and adulticidal properties (Grandi et al., 2010; Bazzocchi et al., 2008; McCall et al., 2008). The antibiotic doxycycline suppresses the heartworm bacterial endosymbiont *Wolbachia* and inhibits the infectivity of L3, making treated dogs less likely to serve as a reservoir of infection or as a source of drug-resistant strains of heartworms (McCall et al., 2008;

Table 4
Heartworm preventive medication provided to dogs in 504 animal sheltering agencies in the Southeastern United States.

	No. of agencies (%)				
	Open-admission shelters	Limited-admission shelters	Foster programs	Veterinary clinics	Sanctuaries
Administration of heartworm preventive	(n = 184)	(n = 137)	(n = 151)	(n = 21)	(n = 11)
All dogs receive preventive	64 (35)	112 (82)	147 (97)	18 (86)	11 (100)
Some dogs receive preventive	41 (22)	10 (7)	4 (3)	3 (14)	0
No dogs receive preventive	79 (43)	15 (11)	0	0	0
Primary reason no dogs are receive preventives	(n = 79)	(n = 15)	(n = 0)	(n = 0)	(n = 0)
Too expensive	46 (58)	10 (66)	NA	NA	NA
Low risk of infection in region	0	0	NA	NA	NA
Takes too much time	0	0	NA	NA	NA
Limited qualified staff	0	1 (7)	NA	NA	NA
Medications not available	11 (14)	1 (7)	NA	NA	NA
Dogs are not tested for heartworm infection	22 (28)	3 (20)	NA	NA	NA
Type of preventive used	(n = 105)	(n = 122)	(n = 151)	(n = 21)	(n = 11)
Monthly canine preventive product	59 (56)	61 (50)	102 (67)	19 (90)	4 (36)
Monthly livestock ivermectin	43 (41)	58 (47)	45 (30)	2 (10)	7 (64)
Daily diethylcarbamazine (DEC)	0	0	0	0	0
Long-acting canine injectable product	0	1 (1)	1 (1)	0	0
Determined by private veterinarian	3 (3)	2 (2)	3 (2)	0	0
Timing of preventive administration	(n = 105)	(n = 122)	(n = 151)	(n = 21)	(n = 11)
After negative heartworm test	46 (45)	61 (50)	99 (66)	12 (57)	4 (36)
When dog reaches minimum age for product	7 (7)	13 (11)	17 (11)	4 (19)	2 (18)
On first day of admission	6 (6)	24 (20)	11 (7)	2 (10)	2 (18)
On a predetermined schedule	25 (24)	21 (17)	22 (15)	3 (14)	3 (27)
After the legal holding period expires	5 (5)	2 (2)	0	0	0
After selection for adoption or transfer to rescue group	16 (15)	1 (1)	2 (1)	0	0
Selection of dogs for preventive medication if not all treated					
Dogs evaluated for adoption or transfer	(n = 41)	(n = 10)	(n = 3)	(n = 3)	(n = 0)
All dogs receive preventive	14 (34)	2 (20)	1 (33)	2 (67)	NA
Some dogs receive preventive	25 (61)	8 (80)	1 (33)	1 (33)	NA
No dogs receive preventive	2 (5)	0	1 (33)	0	NA
Dogs with signs of heartworm disease	(n = 40)	(n = 9)	(n = 2)	(n = 3)	(n = 0)
All dogs receive preventive	4 (10)	5 (56)	0	1 (33)	NA
Some dogs receive preventive	14 (35)	3 (33)	0	2 (67)	NA
No dogs receive preventive	22 (55)	1 (11)	2 (100)	0	NA
Dogs held for cruelty or legal cases	(n = 36)	(n = 7)	(n = 1)	(n = 1)	(n = 0)
All dogs receive preventive	6 (17)	2 (29)	0	0	NA
Some dogs receive preventive	20 (56)	4 (57)	0	1 (100)	NA
No dogs receive preventive	10 (28)	1 (14)	1 (100)	0	NA
Lifelong sanctuary dogs	(n = 9)	(n = 4)	(n = 2)	(n = 0)	(n = 0)
All dogs receive preventive	4 (44)	3 (75)	0	NA	NA
Some dogs receive preventive	4 (44)	1 (25)	1 (50)	NA	NA
No dogs receive preventive	1 (11)	0	1 (50)	NA	NA

Kramer et al., 2008). The use of ivermectin in combination with doxycycline can result in reduction of heartworm burden or cure of heartworm infection sooner than natural death of heartworms, but slower than by melarsomine (Grandi et al., 2010; Bazzocchi et al., 2008).

Most agencies coupled adulticide therapy with other drugs in at least some treated dogs. The most commonly used drugs were selected to eliminate circulating microfilariae and to reduce the inflammatory complications of adulticide therapy, and included doxycycline, ivermectin, corticosteroids, and nonsteroidal anti-inflammatory drugs. Ivermectin was the most commonly used drug in infected dogs not treated with adulticidal intent, but less than half

of these dogs also received doxycycline as recommended by the AHS (Rubin et al., 2010). Recent findings in both naturally infected and experimentally infected dogs as well as in other human and animal filarial diseases suggest that treatment with doxycycline and ivermectin reduces the pathology of filarial infection, regardless of whether adulticide therapy is initiated (Bazzocchi et al., 2008; Grandi et al., 2010; Kramer et al., 2008; McCall et al., 2008; Venco et al., 2004, 2008). If macrocyclic lactones are given to heartworm-infected dogs, doxycycline should also be given to minimize the pathological consequences of infection and to reduce the potential that chronic exposure of heartworms to the drugs will result in selection of drug-resistant

strains of heartworms. Since doxycycline-exposed microfilariae do not develop past the L3 stage, those that survive treatment with macrocyclic lactones cannot contribute to resistance. In addition to saving drug costs, an advantage of avoiding melarsomine in sheltering agencies is that dogs can be moved directly into new homes even in the absence of skilled veterinary services. Although ivermectin is a less expensive treatment and avoids the potential for melarsomine toxicity or acute thromboembolic events associated with adulticide therapy, two studies found that dogs treated with ivermectin alone developed progressive pulmonary pathology (McCall, 2005; Venco et al., 2004). This is likely due to the extended survival of adult worms during ivermectin therapy and underscores the need to restrict exercise in dogs as long as they are infected with heartworms.

The majority of agencies provided at least some dogs with preventive medications. All foster programs, veterinary clinics, and sanctuaries used preventive medication; of these, the vast majority medicated all of their dogs. Agencies with central sheltering facilities, especially open-admission agencies, were less likely to use preventives, and when they did, they were more likely to be selective about the dogs that received them. The most common reason cited for not using preventives was cost. Some agencies indicated they did not use preventives because they did not perform diagnostic testing. Although the AHS urges testing prior to the administration of preventive medication, heartworm infection does not preclude concurrent use of preventives (Nelson, 2009; Rubin et al., 2010). Preventives protect against infection by additional larvae and can also reduce microfilarial counts and the resultant risk of transmission to other dogs. When preventives are used in heartworm-infected dogs, doxycycline should also be administered to help control pulmonary inflammation and to reduce the potential selection for macrocyclic lactone-resistant strains of heartworms. Administration of microfilaricidal preventive medications may induce shock-like signs in dogs with high microfilarial burdens, so guidelines developed to address treatment strategies in animal sheltering agencies should include detailed procedural recommendations to protect canine health. Staff should administer the first dose in the morning, observe for adverse reactions during the day, and be prepared to treat for circulatory collapse and/or anaphylaxis if signs occur. Recurrence of clinical signs following subsequent monthly doses is uncommon.

As was the case for heartworm diagnostic testing, agencies used a variety of priorities for selecting dogs to receive preventive medication, including dogs considered to be candidates for adoption or transfer to other agencies, dogs with signs of heartworm disease, dogs held for legal cases, and those kept in long-term care. Products labeled for use in dogs were administered most commonly, but less expensive livestock ivermectin preparations were used in 155 (38%) of the 410 agencies that administered preventives. Use of livestock formulations can be equally effective, but these are highly concentrated and carry the risk of overdose if not properly diluted. Most of the reports of ivermectin toxicosis in dogs involve overdoses of livestock preparations (Hopper et al., 2002; Merola et al., 2009).

Some respondents mistakenly believed that puppies did not require preventives and withheld medication until 5–6 months of age. The AHS recommends starting preventives no later than 8 weeks of age (Rubin et al., 2010). Failure to provide dogs with adequate heartworm prophylaxis is not limited to animal sheltering agencies. Several studies have demonstrated failure of private veterinary clinics to reliably dispense preventive medication to canine patients (Cummings et al., 1995). In addition, an unknown number of dog owners that purchase preventives subsequently fail to administer them properly. Poor compliance is believed to underlie the majority of lack-of-efficacy cases.

5. Conclusions

Although heartworm infection is considered a treatable condition, the large numbers of infected dogs that enter sheltering agencies combined with insufficient resources may lead to euthanasia of infected dogs that would otherwise be considered adoptable or to the release of dogs with untreated infections. Sheltering agencies currently utilize a variety of management strategies ranging from full compliance with current guidelines to a complete lack of attention to heartworm infection. Many agencies develop their own protocols based on available resources and without the supervision of a veterinarian, sometimes resulting in medically invalid procedures. Specific heartworm management guidelines that are tailored to the unique needs of sheltering agencies and that balance available funding and staffing resources with the medical needs of dogs should be developed. Animal welfare organizations and companion animal health industries should collaborate to improve access to preventive and treatment strategies for management of heartworm infection.

Conflicts of interest

The authors declare no conflicts of interest regarding the content of this paper.

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